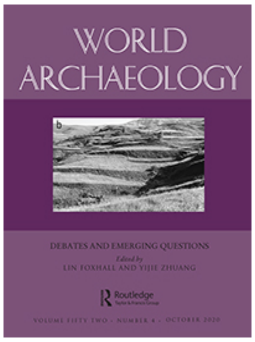

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ARTICLE

European agricultural terraces and lynchets: from archaeological theory to heritage management

Antony Brown[a,b], Kevin Walsh[c], Daniel Fallu[a], Sara Cucchiaro[d] and Paolo Tarolli[d]

[a]Natural Sciences, Tromsø University Museum, Arctic University of Tromsø, Tromsø, Norway; [b]Geography & Environmental Science, University of Southampton, Southampton, UK; [c]Department of Archaeology, University of York, York, UK; [d]Department of Land, Environment, Agriculture and Forestry, University of Padova, Legnaro, Italy

ABSTRACT

Terraces are highly productive, culturally distinctive socioecological systems. Although they form part of time/place-specific debates, terraces *per se* have been neglected – fields on slopes or landscape elements. We argue that this is due to mapping and dating problems, and lack of artefacts/ecofacts. However, new techniques can overcome some of these constraints, allowing us to re-engage with theoretical debates around agricultural intensification. Starting from neo-Broserupian propositions, we can engage with the sociopolitical and environmental aspects of terrace emergence, maintenance and abandonment. Non-reductionist avenues include identifying and dating different phases of development within single terrace systems, identifying a full crop-range, and other activities not generally associated with terraces (e.g. metallurgy). The proposition here is that terraces are a multi-facetted investment that includes both intensification *and* diversification and can occur under a range of social conditions but which constitutes a response to demographic pressure in the face to fluctuating environmental conditions.

KEYWORDS

Agricultural intensification; population density; agricultural sustainability; landscape change; terrace classification; remote sensing

1. Introduction

Agricultural terraces are common on sloping lands on all inhabited continents, from 36°S (New Zealand) to 62° North (Norway). They range in altitude from sea level to over 2,400 m asl in the French Alps and Peru (Apter 2008; Varotto, Bonardi, and Tarolli 2019). Indeed they are the iconic landscapes of the Mediterranean, the Peruvian Andes, the Philippines (Ifugao rice terraces) and the loess of N China (Harlan 1985; Tarolli, Preti, and Romano 2014); a fact now recognized by UNESCO (Wei et al. 2016) through the FAO Globally Important Agricultural Heritage Systems (GIAHS) program (Tarolli and Straffelini 2020). Terracing is often represented as an ingenious, but logical if not prosaic, response to the exigencies of working agricultural land on complex topography. Within the contemporary climate of environmental politics and the need for sustainable agriculture, the widely accepted notion that these systems are resilient has led to a series of research initiatives designed to assess the extent and functional capacities/ecosystem services of terrace systems. This paper explores the theoretical aspects of terrace research focussing on European systems in the light of new scientific methodologies. Here we concentrate on theory and interpretive aspects, but for more detail on scientific methods see a companion paper (Brown et al. 2021).

CONTACT Antony Brown antony.g.brown@uit.no Natural Sciences, Tromsø University Museum, Arctic University of Tromsø, Kvaløyvegan 30, Tromsø 9013, Norway

Mid twentieth century archaeological interest in terraces noted a general correspondence of supposed ancient terracing with centres of agricultural origin and so made an implicit assumption that their origins were *inter-alia* part of the development of Neolithic agriculture (Figure 1). After field-systems, to which terraces have been frequently and understandably related, terraces were the most extensive anthropogenic landscape feature only rivalled by the mass expansion of urban areas, and as such they can be seen as a hallmark of the land-use intensification and the Anthropocene (Ellis et al. 2013; Brown et al. 2016). It is virtually impossible to estimate the global, or even regional, area of land covered by terraces and lynchets, and in only a few cases have attempts been made. In hilly terrains such as Liguria with relatively high village and urban populations, the area covered can reach 30% (Scaramellini and Varotto 2008), although more commonly such as in neighbouring Tuscany it is 4–5% (Agnoletti et al. 2015). More estimates are available for Greek islands such as 70–80% for Keos (Whitelaw 1991), over 90% for Tinos (pers. obs.) and 26% for Antikythera (field systems mostly terraces, Bevan and Conolly 2011). Otherwise, maps have tended to be at the valley scale such as Earl's map of terraces in the Mānoa Valley in Hawaii (Earl 1980) or regions characterized by, terraces such as within Africa (Jensen 1936). A more recent example is the map of Alpine terrace landscapes produced by the APTER Project (Scaramellini and Varotto 2008).

Despite this ubiquity, terraces have received remarkably little archaeological attention until recently. This paper explains why, and goes on to outline a new holistic approach to terrace archaeology within a modern conceptualization of human-landscape relationships, and scientific developments. Part of our assessment also addresses the heritage 'value' assigned to certain terrace systems (FAO-GIAHS assumptions). Today, certain terrace-landscapes are valued both ecologically, and through the 'modern tourist gaze', but it is only recently that research has been able to engage with the complexity of time depth, environmental knowledge and associated forms of human labour needed for a deeper public perception of these keystone systems.

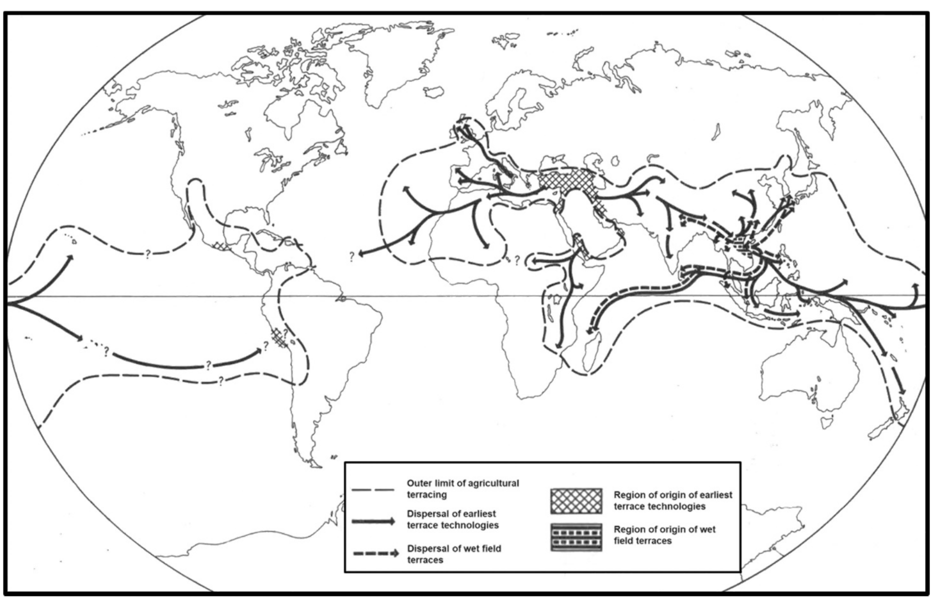

Figure 1. Origins and dispersals of terraces agricultural terracing' according to Spencer and Hale (1961, 33).

2. Previous research

Archaeological research into terraces in Europe has several different geographical and cultural origins and pathways. Globally, interest in the origins of agricultural terracing begins in the mid-twentieth century (Gibson 2017), but the first attempt to trace the origins of terracing was made by W. J. Perry in 1916 (Perry 1916). In the first half of the twentieth century, research was episodic, resulting in a few early publications on Lebanon (Lewis 1953), North Africa (Despois 1956), and the general Mediterranean (Gaussen 1927; Despois 1956). Archaeological interest in ancient terraces was lacking (Bradford 1957) until the publication of 'The origin, nature and distribution of agricultural terracing' by Spencer and Hale (1961), wherein they suggest terraces were developed from multiple regions with the oldest likely being in the Near East (Figure 1). In the 70s and 80s interest in terraces in the New World resulted in new studies (e.g. Donkin 1979; Turner 1983; Keeley 1984; Denevan 1988, Treacy and Denevan 1994; Guillet 1987), although the bulk of research was focused on surveys (Treacy and Denevan 1994). In Europe and the Mediterranean the expansion of archaeological research into terraces began in the 80s and 90s, notably with the work of the Southern Argolid and Berbati-Limnes projects in Southern Greece, which determined that agricultural terracing first appeared in the Late Bronze Age (Van Andel and Runnels 1987). An exception to this is interest in the British Isles, and across Northern Europe into both lynchets and various forms of ridge and furrow cultivation that grew from interest in open-field systems, paysages anthropogéographiques, and Medieval landscape history (Curwen 1939; Froehlicher et al. 2016; Nyssen et al. 2014). Also agronomic interest in the history of terracing is suprisingly early due to the realization that terracing could reduce soil erosion in many areas including colonial China (Smith 1914).

Despite the search for 'origins' – not now a common theme, certain patterns of development undoubtedly can be seen from classic geoarchaeological studies including the critical role of spring-water, floodwaters and forms of irrigation (Doolittle 1990; Van Asperen et al. 2014; Brown and Walsh 2016), pre-existing conditions including erosion and colluviation (Kemp et al. 2006; French and Whitelaw 1999) and the maintenance of fertility (Van Asperen et al. 2014). The social conditions of construction, whilst not being the focus of these studies, do feature where questions are raised concerning the marginal returns from what appears to be high resource (labour) inputs (Goodman-Elgar 2008), or questions of demography and the social context of construction (Bevan et al. 2013; Erickson 2006). This grades into research from a more anthropological direction concerning the socio-political contexts of agricultural intensification, bottom-up vs top-down theories of social organization, and human decision making (Erickson 2006; Thurston and Fisher 2007). Another, probably more tractable, cultural element has been through ideology, religion and aesthetics as in the studies of early Arabic terracing by Butzer (1990) and others (Puy and Balbo 2013; FIlaha Project online). Many, but possibly not all, of these cultural and community factors can be incorporated into more precise and targeted scientific approaches to socioecological systems which can include environmental contexts such as hazards/environmental stress as factors in agricultural intensification (Fitzhugh et al. 2019; Brown 2008).

2.1. Demography, intensification and diversification

Fundamentally all terraces, including lynchets, increase agricultural productivity per unit of planimetric land area. In extreme cases that can be from near zero (grazed but uncultivated hillsides) to 60%+ of planimetric area. Additionally, terracing also allows the cultivation of a wider range of crops, and the raising of more, and different, animals both of which can be seen as beneficial for dietary breadth and so reducing disease and infant mortality (Jones et al. 2016). There are also economic and cultural aspects to this, as crops of greater value or prestige, can be grown, exemplified by the conversion today of many terraces from multi-cropping to vineyards. Since terracing would appear to contravene the least effort principle, it follows that there is a perceived need to increase the type and/or quality of agricultural production and/or reduce risk (Wagstaff 1982; Horden and Purcell 2000). Because of this, terracing is demographically significant, and this has formed a major tenet of terrace theory. The principal reason why the Malthusian model (population outstripping agricultural productivity) 'failed', was due to 'step changes' in land-use intensification (Boserup 1965; Figure 2). Indeed, Broserup directly implicated terracing as one of these step changes (Boserup 1965, 80). It has been argued that although population growth can lead to intensification, including terracing, it need not be accompanied by technological or socio-political change (agricultural 'involution' sensu Geertz 1963). This demographic model has received criticism, on various grounds from mechanistic objections (Cowgill 1975) to emphasize social production and returns (Brookfield 1972). Of particular importance is Brookfield's (1984) concept of 'landesque capital' – investment designed for the long-term as opposed to other forms of intensification of production (Blakie and Brookfield 1987). This is obviously relevant to terraces which have to be the most enduring of all forms of agricultural investment, fortunately for the archaeologist (Bevan and Conolly 2011). This also encapsulates the other values that terraces can have; social, ritual and political. As such they represent the investment of surplus capital and/or labour into an increased level of future production and can so be seen as a risk-mitigating strategy

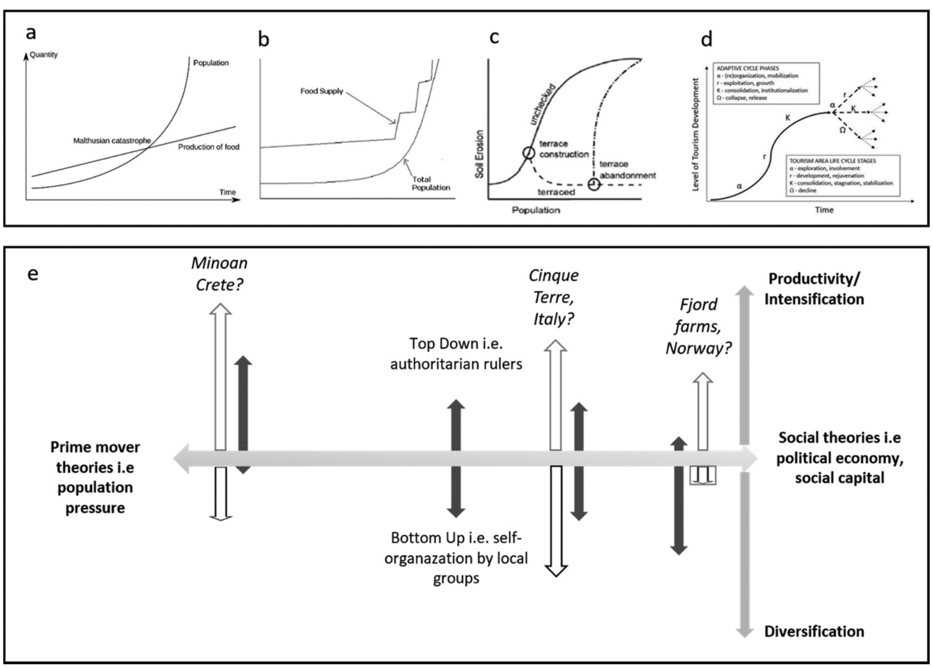

Figure 2. Models of population and terracing. a) the Malthusian model, b) the Boserup land intensification model, c) terrace, population and erosion model, d) adaptive resilience model in which, if maintained, terraces, can retain a level of consistency in returns at a high population level (adapted from Lew 2017) and e) productivity and diversification in relation to the social production continuum adapted from Thurston and Fisher (2007)

allowing the maintenance of higher population levels even in times of economic or environmental hardship (see below). This is also dependent upon the mode of social production (Figure 2(e)) varying in both meaning and probably form, from the state level to the bottom-up efforts of small communities (Doolittle 1990). Some anthropologists, and archaeologists, who have rejected Boserup completely as being reductionist and unidirectional, have emphasized different questions such as individual/community choice, and gender (Van Veen 2005; Thurston and Fisher 2007), social inequalities (Leach 1999), slave-raiding (Widgren 2010) or the trajectories of social complexity (Gilman 1991).

Although intensification has been taken to equal productivity in quantitative, or even calorific terms, qualitative aspects may be just as important, and this is diversification. This can happen through the increase in range of crops that can be grown (e.g. figs as a secondary crop) and animals that can be raised, or folded onto the land. This also has both nutritional advantages and also can produce prestige goods (Horden and Purcell 2000) as part of a local, demand or villa economy, and is one of the fruitful areas for new scientific techniques. Of course, even without increasing yields, terracing can increase food production by a factor related to land slope. In practice, terracing also increases yields per unit area due to moisture retention, and increased fertility as both are directly related to soil depth (Arnáez et al. 2015). So terraces are more productive agricultural systems and can support a higher population density, which is then can become dependent upon the system. This can also create surplus value providing a potential link with increasing population growth and urbanism, such as in the Yemen (Wilkinson 1999). The relationship between terraces and urban expansion has yet to be fully investigated; however, it is noticeable that in many of the villages of the Cinque Terre, Italy, such as Vernazza, the urban form follows pre-existing terrace form with the terraces being under more intensive horticulture close to the village. The creation of terraces was also highly labour intensive – estimates vary (Table 1) but taking the lowest estimates, available figures suggest that terrace construction and maintenance requires a minimum of 12 people ha^{-1}.

The demographics, therefore, raise the testable hypotheses that at various times the creation or re-creation of terraces was part of a positive feedback loop of increasing population density in a non-linear manner (Bevan and Conolly 2011). A non-linear positive feedback loop has been argued for Latin America (Late/Terminal Classic Mayan period, Beach et al. 2002), the Yemen (Bronze Age – third millennium BC, Wilkinson 1999) and the Early Modern period in the Mediterranean (Horden and Purcell 2000; Lasanta et al. 2001; Bevan et al. 2013). Terracing also allowed an extension of activities into new topologically complex landscapes typical of colonialism. Indeed the use (and bringing back into use) of terrace systems in Africa was a popular element in what was seen as a culturally informed development (Grove and Sutton 1989). Whilst these particular demographic hypotheses remain open for testing; it is clear that terracing is another potential indicator of population density along with houses and settlement size, and is potentially superior to demographic proxies such as summed probability density (SPD) of radiocarbon dates. Radiocarbon

Table 1. Estimates of population size required to maintain terracing from various sources.

Location	Basis	Person hours ha^{-1} yr^{-1}	Pop km^{-2}	Reference
Europe	Historical population density estimates	600–1200	~ 20–40	FAO 2013
Trevélez municipio, Andalucia Spain	Historical population decline and terrace abandonment	-	13	Douglas, Critchley, and Park 1996
Mediterranean	Required to construct terraces within 10 km^2 17th-ninteenth AD	-	26–166	Blanchemanche 1990
Camero Viejo, Spain	Terrace maximum, late ninteenth AD	-	17	Lasanta et al. 2001

derived demographic (SPD) models are now more sophisticated and appear to be producing data that is not only of high utility, but fits with other data on settlement expansion and contraction in the Mediterranean (Roberts et al. 2019; Weiberg et al. 2019; Bevan et al. 2018; Berger et al. 2019).

Terracing must also be seen in relation to local social and political control manifest through land ownership, tenurial arrangements and taxation. The manipulation of water resources that is such a conspicuous element in many Mediterranean terrace systems is part of political and ideological control, but can also be part of local negotiation and conflict at the level of the individual farmer, as portrayed in classic work of French literature 'Manon des Sources' (Pagnol 1953). As in the case of Stymphalos in the Peloponnese, this can include an element of geomythology and the demands of the urban elite (Walsh et al. 2017). The relationships of terracing to settlements, including defended settlements, can be multi-factorial, through population but also through the use of terraces as transport routes, and as house sites as settlements expand.

The development and form of terraces also contain potential information on the developmental history of the system. Whilst it often appears that terraces must represent communal and collective workscapes – this can be within a variety of socio-political contexts. To engage in debates concerning top-down vs bottom-up agricultural intensification (Thurston 2006; Erickson 2006) a landscape approach is required and the recognition of phases of development and relationships to non-agricultural features that may indicate the cultural context and influences. This is highly relevant to the examination of the non-linear relationship between climate change and erosion and the often stated proposition that terracing was a development designed to control slope erosion (Vanwalleghem et al. 2017; Brown et al. 2021).

2.2. Terrace and lynchet archaeology

There is little doubt that agricultural terracing existed in Europe and the Mediterranean during the Greco-Roman period, but how common it was is a matter of dispute (Price and Nixon 2005; Foxhall 2011). It has been claimed that terracing is virtually absent in Classical Greek literature but, as Price and Nixon (2005) argued that might be due to a failure to recognize the semantic breadth of common terms (of, e.g. *αἱμασιά*) and textual omissions, rather than a lack of real commentary. Foxhall (2011) also points out the problem of terrace invisibility due to obliteration by modern terracing, rendering them undatable – which is a strong case for improved dating. Classical Roman literature and instructions on how to lay out trenches around trees are found in Columella's *De re rustica* but not terraces contrary to Olson 1943; Foxhall 1990). Although there was Roman taxation of land (*Tributum soli*, Gunther 2016), there was no specific taxation of terracing.

2.3. Terrace classification

Terrace research has emphasized the description of terrace form, spatial extent, crops grown, and most recently dating. We need a classification system for terracing for the assessment of functional characteristics, resilience, sustainability and the technologies, skills, labour and time involved in terrace creation and maintenance. We aim not merely to understand terraces as an economically rational socioecological endeavour, but also understand the position of terraces vis a vis systems of political control and social structure. Terracing, of course, varies in form and construction due to both natural and cultural factors. Important early developments in terrace archaeology comprised attempts to classify terraces by Grove and Rackham (2001) and others (Krahtopoulou and Frederick

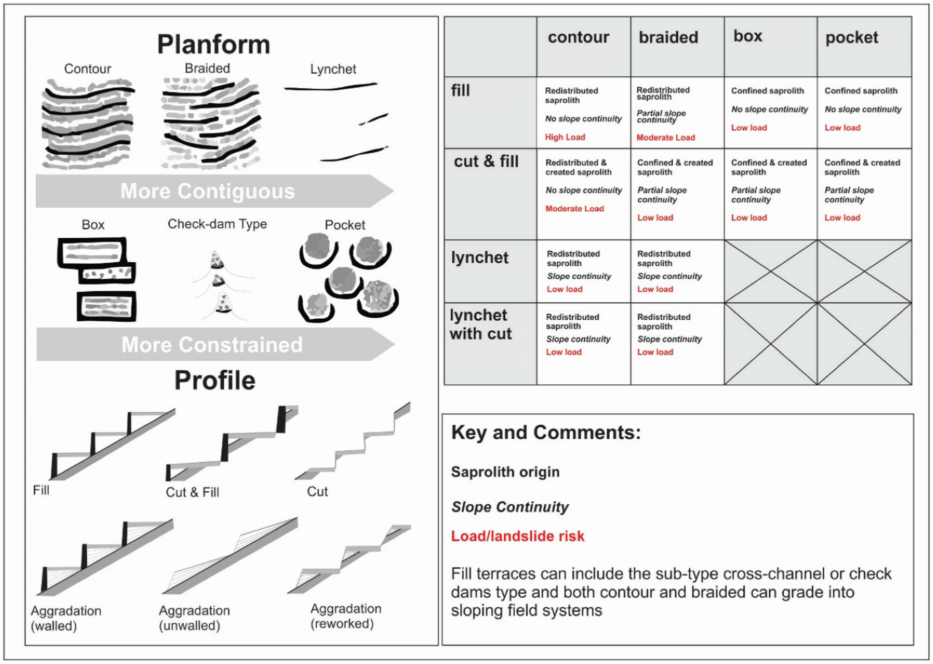

Figure 3. The classic terrace and lynchet classification, adapted from Grove and Rackham (2001), and modified by Krahtopoulou and Frederick (2008) with lynchets from Wood (1961). The unwalled type includes, but is not restricted to, lynchets but there is some confusion over the use of this term (see the text).

2008; Wei et al. 2016; Chen et al. 2020). A comprehensive classification should include both planform and long-section parameters but also should be as simple as possible (Figure 3).

A classification based on both plan and section more effectively discriminates terraces from lynchets and walled from un-walled and cut-and-fill terraces. The check-dam form frequently contains naturally deposited fluvial sediments and can be easier to date (Dennell 1982). Classic twentieth-century considerations of terraces (Guzman 1958; Swanson 1955; Spencer and Hale 1961; Field 1966; Doolittle 1990) were concerned both with variety of form but also the relationship of terraces to the spread of agriculture (Figure 1). So the problem of reliably dating terraces and especially terrace origins, was a principal reason for a lack of later research (Acabado 2009; Kinnaird et al. 2017). However, we argue here that the dating problem was not the only reason for the neglect. Although rarely voiced, agricultural terraces are often seen as 'boring' due to not being 'structures', or associated with finds that have chronological or cultural value. Not being shrines, temples, palaces, houses or tombs excavation could not easily be justified. Terraces had to wait for the rise of landscape archaeology in the later twentieth century before receiving renewed if limited interest (e.g. POPULUS and ARCHAEOMEDES). Indeed terraces are prime examples of the palimpsests that characterize landscapes at a variety of spatial scales (Adams 1990; Gillings, Mattingley, and van Dalen 2000; Walsh 2013). That landscape archaeology did not lead to a widespread resurgence in terrace archaeology in the 1990s was again principally due to the problems of ^{14}C dating terraces (lack of material and/or reworking). There were, however, pioneering uses of environmental techniques such as lipid analysis (Bull, Betancourt, and Evershed 2001). The result of this neglect has been the relative absence of terraces from standard student texts where there are typically some references to terracing, but little analysis or discussion although the difficulty of dating is often mentioned (e.g. Renfrew and Bahn 2016; Broodbank 2013).

2.4. The rise and fall of lynchets

Whilst small steps, or terraces on slopes without walls, come under all general definitions of terraces (excluding grazing terracettes) they have by convention been given a separate identity with their own term in many regions with the English term being lynchets (Table 2). One recurrent theme, or question, is whether lynchets can be characterized as an or 'accidental' form of slope mitigation created unconsciously (Froehlicher et al. 2016). However, the term lynchet is problematic. Although most commonly thought to have been derived from 'hlinc' Anglo-Saxon for a ridge or bank (originally used for natural features and the same derivation as 'links' golf courses) and it was first used for cultivation ridges in the eighteenth century and then by ninteenth century map makers, and notably by the British Ordnance Survey (Wood 1961). This led to it being used on maps for almost all terrace-like features in the British landscape. So the term has been used very widely ranging from the build-up of soil behind a Neolithic wall (Verrill and Richard Tipping 2010) to cut and fill terraces that cannot have been created by either natural processes or ploughing (Figure 4(a)).

Lynchets are such a common feature, along with ridge and furrow (or rig and furrow) across Northern Europe that they received early interest from cartographers, geographers and Medieval archaeologists in the twentieth century. In a classic study, Curwen (1939) reconsidered the generally accepted origin of lynchets as being created by ploughing between baulks on slopes in open field systems (Orwen and Orwen 1938). He pointed out that the dimensions, particularly the riser, which could be up to 3 m (20 ft), were too great to have been created by this process alone and that not all lynchets were associated with open field-systems. What Curwen (1939) effectively did was differentiate large lynchets that had to be created as terraces (but without walls) from cultivation lynchets that could be created by ploughing strips successively in one direction. An example of such terraces mapped by the OS as strip lynchets is the classic site at Mere in Wiltshire, England which in form are almost identical to the unwalled-braided terraces at Villar d'Arêne (Figure 4(a,b)).

Table 2. Some regional terms for European agricultural terraces, lynchets and similar anthropogenic landforms. The regional use of etymologically different words suggests local development in some cases and in others an unknown origin.

Term	Language/country	Literal meaning/derivation	Reference
Cadenas	Spanish, Canary Isles	Chains	Lidia, Morales, and Ojeda 2016
Casoni	Italian, Liguria	Terraced seasonal farms	Stagno 2016
Walls	England, used to describe terraces too big to be lynchets and colloquially used	Form	UK Ordnance Survey
Siderigg	Cultivation terraces used in N England	Ridges (rigg) along a slope	e.g. Eggleston, Co. Durham
'Lynchets'			
Ackerterrassen	German	Ploughland (lynchet)	Lóczy. 1998
Rideau de culture	French	Lynchets (not intentional)	Froehlicher et al. 2016
Graaf, graft, graf	NE Belgium, S Netherlands, W Germany	From digging	Nyssen et al. 2014
Royon	France	Furrow	
Rideaux	France	Literally curtains (although defined as the unintentional arrangement of a slope)	Blanc 2019

Figure 4. (a) photo of braided-unwalled (lynchets) from near Mere, England (photo by A. Brown), (b) photo of the braided-unwalled terraces Villar d'Arêne (French Alps) taken in June 2019 (photo by K. Walsh).

However, many strip lynchet systems are much less extreme and can be shown to be related to ridge and furrow systems which are Medieval in date (Hedley 1931; Brown 2006). After early interest, which included some excavations (Curwen 1939; Whittington 1962), interest in lynchets dwindled. The reason is that the archaeological study of lynchets suffered from the same problems as terraces in general. A partial revival in the last 20 years (Ford et al. 1990; Sillar, Sommer, and Davis 2008; Nyssen et al. 2014) has been stimulated by landscape surveys of field systems, an interest in colluviation (Brown 1992, 2006) and a greater appreciation of the processes of tillage erosion which can mobilize surprisingly large quantities of soil, and more than natural erosion (Govers et al. 1994; Quine et al. 1999).

From a preliminary database of 92 published sites of which only approximately 10 have robust dating (Figure 5) we can see that studies have been heavily concentrated in four Mediterranean countries (Spain, Italy, Greece and Israel). Northern European terrace studies are rare and predominantly in the UK and Scandinavia probably partly reflecting a shared archaeological tradition in landscape archaeology. It appears that although examples of terracing have been studied from as

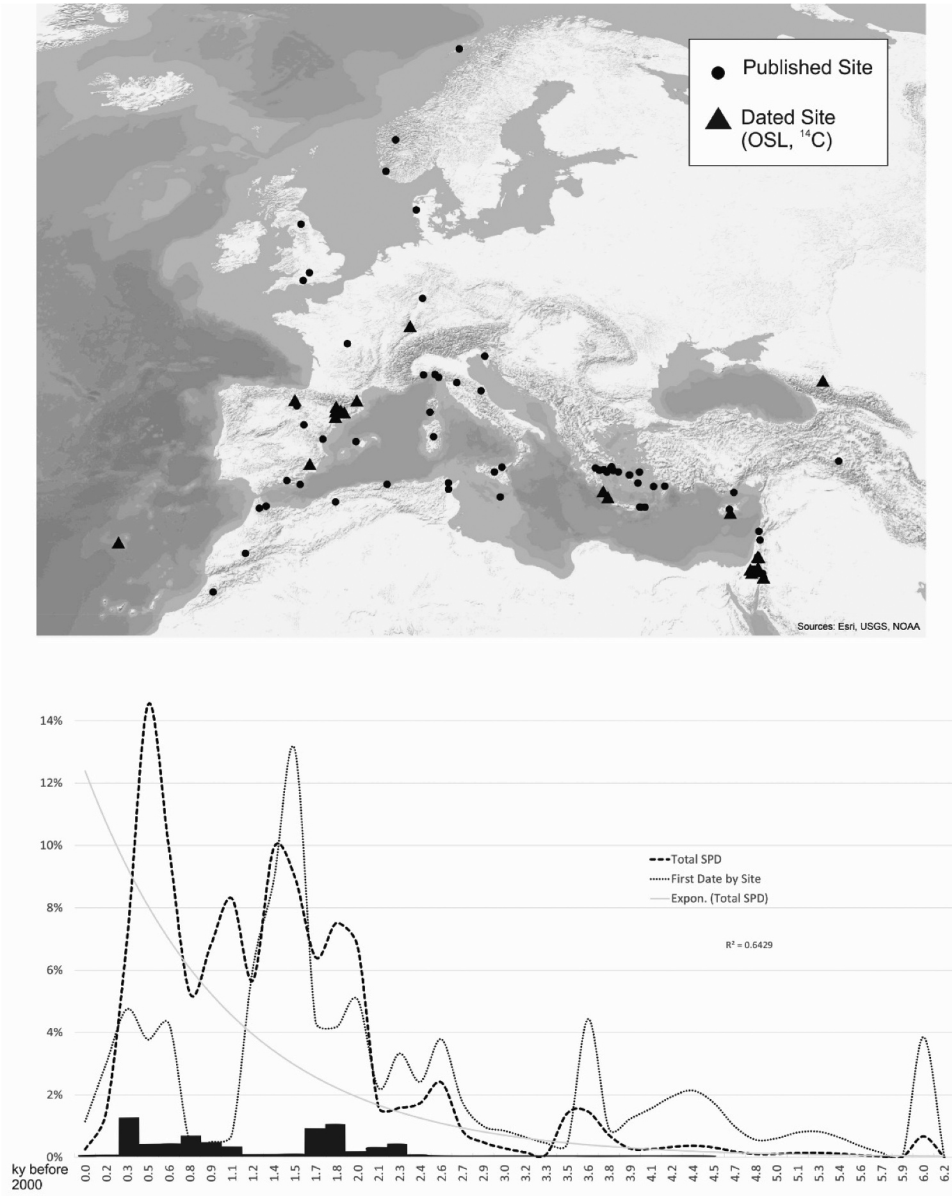

Figure 5. Top: location of 92 published sites and regional archaeological studies of terraced landscapes with triangles being sites with OSL dating. Bottom: the summed probability density function of all dates (^{14}C and OSL, N = 173) and using only the first date by site (n = 26). Three sites in Yemen, representing some of the earliest known terraces, are also included in the counts.

early as the Neolithic-Bronze Age, these are rare and most that have been studied date from the Roman period (c. AD 0/2.0 ka years BP) to the Post-medieval period with a pronounced peak around AD 1500. The rapid fall-off to the present is probably the result of a lack of studies and problems of dating very recent terraces; however, there is also relatively little evidence of terraces being created in the last two centuries but the extent to which this is a product of dating techniques needs to be fully evaluated. The surprisingly good fit of the exponential model is a proxy measure of the population supported by terraces and but which is probably less steep an increase than the population that terraces could support due to both intensification (increased productivity per ha) and diversification.

3. Terracing and environmental change

The effects of creating terraces on slopes include an increase in rooting depth, soil moisture storage, and fertility due to both the incorporation of organic matter into soils and its pathways of decomposition, microbial activity and in theory increased weathering. This amounts to a positive contribution to ecosystem services (ES). Due to the thickening of the soil created by terracing, these effects are largely automatic – so are emergent properties of the terrace system; or, as Horden and Purcell state, terraces work through a 'sympathetic adaptation to geomorphological processes' (Horden and Purcell 2000, 235). These do not have to be managed *per se* or even understood, since they are just the emergent properties of the modified soil system that will persist until the walls collapse (Figure 2(c)). The situation is a little different in the Americas where the lack of ploughs means that it is more likely that terraces were primarily designed to retain soil moisture and any reduction of erosion is an incidental gain (Donkin 1979; Beach et al. 2002). The importance of terraces in determining local erosion rates has led to what Brown and Walsh (2016) have termed the archaeology-soil erosion paradox. This is the question of how ancient societies survived in environments in areas with high natural erosion rates – one of the major mechanisms being terrace creation and maintenance. Terraces introduce a non-linearity into the relationship between climate, vegetation cover and soil erosion which creates resilience if the terraces are maintained. In essence, well built and maintained terrace systems can maintain resilience at a high population level and develop the capital so valuable for socio-political power as shown for the ancient Maya at Waybil, Belize (Macrea 2017). It is now possible to use sediment transport models, particularly for check dams or silt-traps, to examine the timescales and sequencing of terraces (Kabora, Stump, and Wainright 2020). As shown in Figure 2(c,d) if terracing is not maintained, or abandoned then it can, of course, flip from an ES positive to a hazard (Tarolli, Preti, and Romano 2014). This is of societal importance as it determines if the maintenance or re-use of terraces really can be an efficient adaptation to climate change (Bocco and Napoletano 2017; Londono, Williams, and Hart 2017). Sadly, similar calls for investment in the widespread and ancient terracing in the Yemen three decades ago (Varisco 1991) were unheeded by the international aid organizations and fell foul of regional-international politics.

3.1. Archaeology and heritage management

Terraces, in many ways, typify the dichotomy of the Anthropocene. They are obvious examples of extensive and direct human intervention in the geomorphic system, changing the natural topography and associated sedimentary processes. However, they are the quintessential example of a resilient socio-environmental system often of some antiquity. The danger is, once terraces are no longer maintained, their collapse can be disastrous for the soil system (Tarolli, Preti, and Romano 2014; Paliaga et al. 2020).

There are a number of terrace systems identified as heritage spaces. Along with Cinque Terre in Italy, perhaps the most enigmatic UNESCO rural landscape within a European context is the Lavaux Vineyard Terraces on the northern shores of Lake Geneva. Listed in 2007 (UNESCO World Heritage Centre – Decision – 31 COM 8B.46, n.d.) this landscape was inscribed for a range of reasons, including the fact that it has developed as a sustainable and highly visible manifestation of a thriving agricultural landscape. The definition of heritage value goes beyond aesthetics, and terraced landscapes are assigned value because they represent 'harmonious interaction(s) between people and nature' (Gullino and Larcher 2013, 393). There is little doubt that many people who reside in these landscapes today share a sense of pride, and the World Heritage 'appellation' is often an effective marketing tool and boost for agri-tourism. However, certain forms of heritage value and classification are founded on middle-class urbanite assumptions that rural populations want to maintain and exploit their terrace landscapes (e.g. some residents of Villa d'Arêne are glad that they do not have to undertake back-breaking work on terraces, to Walsh pers. com. 2019). In addition, we forget that the history of terrace systems, especially those that were producing valuable crops, was often underpinned by complex systems of peasant labour, taxation, and in some cases coercion. Many 'valued' terrace systems, including those in parts of the south of France, were integral elements of agrosystems that supported the highest rural population densities ever seen. Since the nineteenth century, these densities have waned: do we now let these systems collapse, or is there an argument for maintaining them if only from the ecological perspective?

Given the aim of terracing, thickening soils and retaining organic matter and moisture, it is clear that terrace systems are likely to increase carbon sequestration and reduce soil erosion (Chen et al. 2020). However, there are few measurements of this in Europe at present, so its total significance cannot be estimated. Hence an important component of the TerrACE project is the estimation of both the quantity and stability of carbon locked-up in terrace systems. This can then form one element in an overall assessment of terraces' role in any particular landscape for management purposes (Paliaga et al. 2020). This requires a comprehensive suite of modern field and laboratory methods and an interpretive strategy informed by the environmental humanities. Such research should not only reveal the long-term history of a terrace system (Varotto, Bonardi, and Tarolli 2019, 37), but it should also hopefully reveal the complexity and heterogeneity of the agricultural practices and crops associated with the social system. More importantly, this deeper science and humanities-based analytical framework constitutes a package that can be deployed across non-European landscapes and contribute to a more equal distribution of rural World Heritage sites across all continents.

4. Towards a scientific and socially integrated approach

All approaches to terrace archaeology start from accurate 3–4D (i.e. space + time) models of terrace systems. Here we present the first steps in our analytical approach, i.e. the use of remote sensing and terrace extraction algorithms. This can then be combined with cadastral data (Figure 6), direct sediment dating and palaeoecology along with contextual historical and archaeological information (Brown et al. 2021). The recent convergence of remote sensing, particularly LiDAR and TLS (terrestrial laser scanning, with new sediment-based dating techniques (particularly sediment luminescence dating) and land-use proxies, have finally provided a suite of analytical techniques that can tackle the terrace problem. Terraces, including abandoned terraces, can now be mapped using high-resolution digital elevation models (DEMs) derived from LiDAR (Figure 6(a)), with the capability of detecting bare ground soil even on vegetated treads, or by using the aerial structure from motion (SfM) photogrammetric technique (Tarolli 2014; Eltner et al. 2016; Cucchiaro et al. 2020). The combination of high-resolution aerial photographs and GIS is now used routinely to map terraces for management purposes (Agnoletti et al. 2015). The development of algorithms for extracting terrace sizes/volumes can then be integrated with information from 'cadastres' or land-holding data

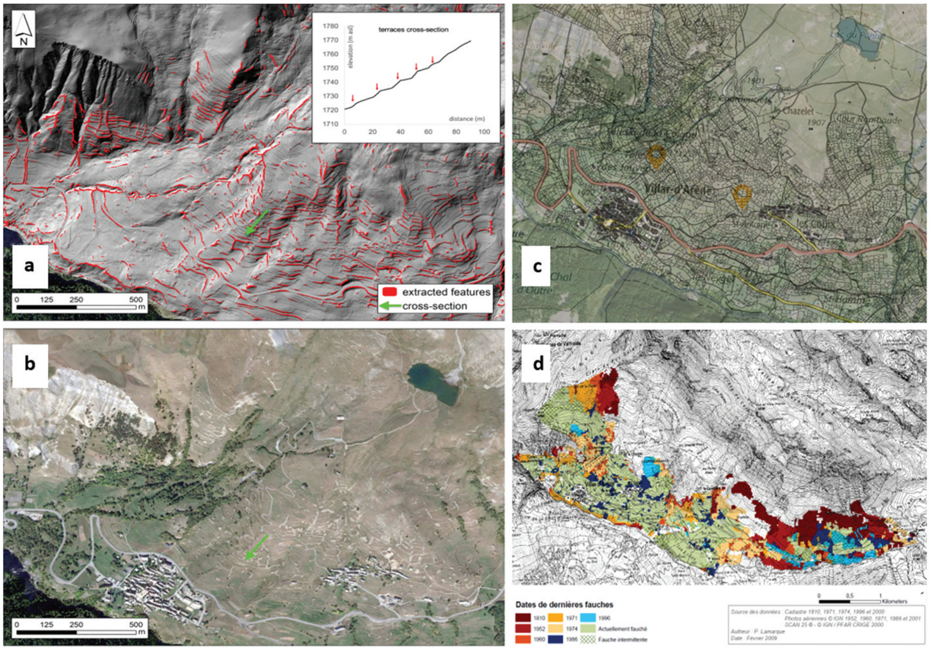

Figure 6. Terraces and linear forms at Villar-d'Arêne (French Alps). a. as extracted from a 2m LiDAR-derived DEM using the methodology of landform curvature outliers presented in Sofia et al. (2014b) and Tarolli et al. (2014). Lidar survey by Sintégra, Meylan, France for Université Grenoble Alpes. Survey date: August 16-17, 2012 using a Riegl LMS Q680i flown in a Cessna 206. Meteorological conditions: clear sky, light wind (10 kts). Flight height: 610 m, Flight speed: 60 kts, Swathe of band: 704 m, Scan angle: 60 °, Altimetric accuracy (standard deviation): 10 cm, Planimetric accuracy (standard deviation): 25 cm, Total density of points: 20 pts / m^2, Ground point density after filtering: 7 pts / m^2. b. the same area derived from Google Earth © Google. c. part of the cadastral map of the same area from Girel et al. (2010). d. A map of the last mowing of hay (dates de derniéres fauches) and the continuing mowing (actuaellement fauché) and intermittent mowing (fauche intermittente). For more information on the historical land use history see Girel et al. (2010).

thereby facilitating investigations of the relationships between ownership, terrace-type, terrace use (monoculture, mixed crops, pasture etc. (Blanc 2019, 64)) and taxation (Table 3). Terraces show a much sharper and more linear shape than natural terrain features (Sofia, Mariniello, and Tarolli 2014a), and, consequently, they represent outliers within the derived geomorphometric parameters (e.g. surface derivatives such as curvature). Statistical analysis of variability of surface derivatives probability density functions can be used to identify a statistical threshold for geomorphic feature extraction (Tarolli, Sofia, and Dalla Fontana 2012). Sofia, Dalla Fontana, and Tarolli (2014b) used the boxplot approach (Tukey 1977), and identified outliers as those points verifying Equation (1).

$$C_{max} > Q_{3_{C_{max}}} + 1.5 \cdot IQR_{C_{max}} \tag{1}$$

where C_{max} (Wood 1996) is maximum curvature calculated by solving and differentiating a quadratic approximation of the surface as proposed by Evans (1979), $Q_{3_{C_{max}}}$ and $IQR_{C_{max}}$ are the third quartile and the interquartile range of C_{max}, respectively. Figure 6 shows an example from Villar d’Arêne in the French Alps of the topographic features (~terraces) derived after thresholding, according to Equation (1), C_{max} calculated using a 2 m lidar-derived DEM.

Table 3. The 3-year rotation (top) and land use organization in AD 1828 at Villar-d'Arêne, in both English and French, adapted from Girel et al. (2010).

Rotation Year	Rotation Crop 1–3		
1st year	Fallow (*jacherie*)	Rye (*seigle*)	Spring cereal crops: wheat/oat/ barley (*Culture de printemps trémois*)
2nd year	Rye (*seigle*)	Spring cereal crops: wheat/oat/ barley (*Culture de printemps trémois*)	Fallow (*jacherie*)
3rd year	Spring cereal crops: wheat/oat/barley (*Culture de printemps trémois*)	Fallow (*jacherie*)	Rye (*seigle*)
	Land use	Coverage (ha)	% of the total area
Taxable (*imposable*)	Arable land (*terres labourables*)	177	6.1
	Gardens/horticulture (*jardins*)	1	0.03
	Mown meadows (*prés fauchés*)	332	11.4
	Orchards and plantations (*vergers et plantations*)	0	0
	Woodland (*bois*)	9	0.3
	Pastures, not mown (*pâtures, non fauchés*)	788	26.9
	Larch wood with rocks (*bois de mélèze avec roches*)	29	1.0
	Wasteland, rocky areas probably risers and clearance piles (*friches, terres vaines, rocailles*)	1579	54.0
	Made-ground, probably risers (*sol bâti*)	9	0.3
	Total taxable (*Total imposable*)	2924	35.3
Non-taxable (*non-imposable*)	Routes, roads, junctions (*routes, rues, places*)	27	0.5
	Rivers, lakes/ponds (*rivières, lacs*)	100	1.9
	Other (*autres*)	5232	97.6
	Total non-taxable (*total non imposable*)	5359	64.7
Total area (*superficie totale du territoire*)		8283	

The DEM and automated extraction of terrace forms from Villar d'Arêne is used to estimate physical parameters such as slopes, riser heights and plot size, wall length and parcel density. The resultant terrace maps also contain some temporal data with identifiable cross-cutting relationships and variations in form, suggesting non-contemporaneous development which can be tested by the dating programme. From the estimation of soil volumes, drainage, and insolation, it is also possible to estimate crop suitability and productivity. The questions we can ask of this data unsurprisingly echo the themes articulated earlier, particularly questions relating to demography and social organization. We know relatively little is known about the prehistory of landscape use in the Villar-d'Arêne area. Work in the Ecrins demonstrates that high altitudinal zones were exploited from the Bronze Age onwards (Walsh et al. 2014, 2010); however, there is no direct evidence attesting to such activity around Villar-d'Arêne, although a cache of Bronze Age metalwork (at 2000 m) was found in 1963 (Courtois 1966). Noting its situation adjacent to the Col du Lautaret on an important routeway between the Durance and the Oisans (Jourdain-Annequin and Le Berre 2004; Rochas 1998), there is little doubt that Villar-d'Arêne witnessed early agricultural activity (Bocquet 1983). By the Roman period, we know that these areas were exploited, with a network of towns and villas spread across the Brianconais (Segard 2001).

We see how over 90% of the terrace system is on the northern side of the road, observing the usual alpine agricultural configuration with arable and hay meadows facing southwards for maximum insolation. It is possible that the establishment of field and terrace systems is contemporary with the village's establishment, this dating back to the twelfth or thirteenth centuries, and probably much earlier. With the village as the point of origin, the hypothesis is that terrace construction expanded to the north and upslope as the local economy developed with the northern limits likely developed from the late fifteenth century onwards, during the post-plague demographic rebound seen in many western alpine regions, including the Isère (Mathieu and Vester 2011). We know more about the Medieval and post-Medieval historical periods, and in comparison to other mid-northern latitude mountainous areas, there was a diversity of cultivation strategies in this part of the Alps (Dodgshon 2019, 43). Our LiDAR and extracted terrace/parcel model allows us to consider the complexity of land management and local political organization. The small parcel sizes seen in Figure 6(c) represent a land division system whereby individuals in the commune owned parcels across different parts of the mountain slope. This agricultural mosaic was, in part, a function of the diverse range of ecological characteristics (insolation, hydrology, soil quality etc.) possessed by different areas across the slope/terrace system. Areas with better growing conditions were probably given over to crops with groups of parcels in each ecological zone owned by different members of the commune and which would be in different stages in the rotational system that was certainly in use in the ninteenth century (Table 3). Complex terrace parcel systems with common cropping or forage production zones undoubtedly saw cooperation when it came to harvesting and hay-making (Dodgshon 2019). The outer edge of the terrace system was often given over to pasture, which was certainly the case during the nineteenth century when population levels were at their highest (Girel et al. 2010). While much communal summer pasture was at a higher altitude, beyond the terraces, the creation and maintenance of pasture close to the village were important.

Returning to the posited links between demography and terrace construction, we are reminded of Malthus' observation 'There are no grounds less susceptible of improvement than mountainous pastures' (1878, 172): a notion that we can question. It is already apparent that the terrace system at Villar is highly adaptable, having evolved through time, with the commune adapting to internal needs and external pressures with ecological consequences (Lavorel et al. 2011). One of the reasons for focussing on this system is the preservation of DNA from cultivars in terrace soils as determined by Yoccoz et al. (2012) from terraces that went out of crop production between AD 1810 and AD 1986 (Lavorel et al. 2011; Schermer et al. 2016; Yoccoz et al. 2012). This short case study reveals the potential for the first stage in our framework. Subsequent excavation, sediment-based dating and analytical work will further this spatial and historical framework. The application of techniques, particularly optically stimulated luminescence (OSL), has driven a resurgence of interest in terraces (Gibson 2015; Gibson and Lewis 2017; Gadot et al. 2016; Kinnaird et al. 2017; Brown et al. 2021) and offers for the first time an archaeologically independent way of documenting the life-histories of terraces and lynchets (Dennell 1982).

5. Conclusions; intensification, diversification and resilience science

Agricultural cultivation terraces in Europe were created using different techniques, at different times by different peoples for different reasons, over at least the last 8,000 years. Terraces also have their own life histories resulting from changing social, political and perhaps environmental pressures. However, the stimuli, trajectories, environmental and social contexts can be comparable and so cross-cultural analysis has value in understanding the evolution of agricultural terraces, and human response to both internal and external forcing of change, even under different conditions of social production. Terraces, irrespective of their original purpose, are also pre-eminent examples of positive human-environmental feedback systems that maximize food and human potential and provide environmental benefits in the form of reduced erosion and increased carbon storage. However, they are also potentially prone to tipping points – whereby if abandoned, the whole process goes into reverse with overall negative consequences at the regional and even potentially global level. In this paper, we have discussed why terraces (and lynchets) have been relatively ignored in archaeology, some categorical problems, and how we can conceptualize and theorize the study of terraced agricultural landscapes as both landscapes of intensification and diversification. Do periods of demographic pressure stimulate terrace construction and periods little terrace construction relate to lower demographic pressure? What is the relationship between deforestation, stone-clearance, terraces and systems of social production? To what extent are terraces examples of both intensification and diversification?

The theoretical proposition outlined here is that terraces are a multi-faceted, non-linear response to demographic pressure but triggered by multiple possible social scenarios including climate change, conflict, migration, urbanism, coercion etc. We also suggest that terraces allowed sustained high population densities even in the face of environmental stress – thus resolving the soil-demography paradox. Testing these questions and hypotheses are timely as terraces are an important part of heritage landscapes and are, in many areas, of marginal economic value rendering them susceptible to abandonment and destruction. If we are to argue for their retention as part of heritage landscapes, we should know their socio-political history, understand their human requirements and the full range of their potential uses and value – ranging from crop diversification to soil carbon storage. The conceptual framework of agricultural intensification, diversification and resilience theory provides a new theoretical platform, but it is new scientific methods that can end the Cinderella status of terraces in archaeology.

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Notes on contributors

Antony Brown is Research Professor at the University Museum, Arctic University of Norway, Tromsø, Norway and Professor in the Department of Geography and Environmental Science at the University of Southampton, UK. His research is interest are in geoarchaeology, geomorphology and environmental archaeology. He is author of *Alluvial Geoarchaeology* (1997, Cambridge University Press) and over 200 research papers in internationally reviewed publications. His most recent projects have concerned wetland and lake villages, the environmental history of coastal islands and Northern Norway, and the geoarchaeology of European agricultural terraces. He is both a fellow of the Geological Society of London and the Society of Antiquaries.

Kevin Walsh is Reader in Landscape Archaeology at the University of York. His research interests broadly deal with mid-late Holocene human-environment interactions in Mediterranean mountains. He has carried out extensive fieldwork in the Southern French Alps, Provence and the Peloponnese. He has published widely on all these themes, including a single-authored volume: *The Archaeology of Mediterranean Landscapes: Human-Environment Interaction from the Neolithic to the Roman Period* (2014, Cambridge University Press). He is also co-editor of *Geoarchaeology* – An International Journal, published by Wiley.

Daniel Fallu is a Postdoctoral Research Assistant at the University Museum, Arctic University of Norway, Tromsø, Norway. His research is geoarchaeology and the history of landscape change and management, with a particular focus on the Mediterranean. Trained as a soil/sediment micromorphologist he has undertaken extensive geoarchaeological work in Greece, Italy and Norway. His current research focuses on the formation and use history of agricultural terraces and lynchets in Europe.

Sara Cucchiaro is post-doc researcher at the Department of Agricultural, Food, Environmental and Animal Sciences of the University of Udine. During her PhD project, she worked on high-resolution topographic technologies to study sediment dynamics in mountain catchments. Her research has focused on geomorphological analysis and monitoring of the environmental processes by exploiting Digital Terrains Models realized through aerial and terrestrial photogrammetry, GNSS, and laser scanning surveys.

Paolo Tarolli is Professor in Integrated Watershed Management and Water Resources Management, and Principal Investigator of Earth Surface Processes and Society research group at University of Padova (Italy). He is expert in digital terrain analysis, earth surface processes analysis, natural hazards, geomorphology, hydro-geomorphology, lidar, structure-from-motion photogrammetry; new research directions include the analysis of topographic signatures and impact of human activities, focusing on agricultural landscapes & land degradation. He is author of 130 papers published in international peer reviewed journals. His most recent projects have concerned Innovative solutions for soil erosion risk mitigation and a better management of vineyards in hills and mountain landscapes, agricultural terraces mapping, pasture degradation in mountain context.

ORCID

Antony Brown http://orcid.org/0000-0002-1990-4654
Kevin Walsh http://orcid.org/0000-0003-1621-2625
Daniel Fallu http://orcid.org/0000-0002-6717-473X
Sara Cucchiaro http://orcid.org/0000-0002-8042-836X
Paolo Tarolli http://orcid.org/0000-0003-0043-5226

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